

## SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT WE, TAKASHI KITAGUCHI, a citizen of Japan residing at Kanagawa, Japan, YASUHIRO SATO, a citizen of Japan residing at Kanagawa, Japan and NORIHIKO MURATA, a citizen of Japan residing at Kanagawa, Japan have invented certain new and useful improvements in

APPARATUS AND METHOD FOR CORRECTION OF A DEVIATION OF  
DIGITAL CAMERA

of which the following is a specification:-

1     BACKGROUND OF THE INVENTION

          (1) Field of the Invention

          The present invention relates to an  
apparatus and a method for correction of a deviation of an  
5     imaging sensor of a digital camera which may be produced  
by a slight oscillation of the human hand in taking a  
photograph using the digital camera.

          (2) Description of the Related Art

          Recently, the rapid growth of digital  
10     cameras for business uses as well as for personal uses has  
been experienced. Developments of digital cameras having  
a small size and a light weight with low cost will be  
increased. With the developments of such digital cameras,  
attention will be focused on correction of a deviation of  
15     a digital camera caused by a slight oscillation of the  
human hand when taking a photograph with the digital  
camera.

          If an imaging sensor of the digital camera  
deviates from a reference position due to the oscillation  
20     of the operator, a dim image will be reproduced by the  
digital camera. If the deviation of the imaging sensor is  
not corrected, it is difficult for the digital camera to  
provide good quality of a reproduced image. Therefore,  
there is a demand for a digital camera which is capable of  
25     automatically correcting a deviation of the imaging sensor

1     which may be produced by a slight oscillation of the  
operator who takes a photograph with the digital camera.

       In the fields of video cameras, techniques  
for correction of an image deviation of the video camera  
5     are known. For example, Japanese Laid-Open Patent  
Application No.64-78581 discloses a video camera deviation  
correcting device. This deviation correcting device  
includes a frame memory which stores an image signal. An  
image deviation caused by a camera deviation is detected  
10    from a difference in image data between two frames in a  
sequence of continuously processed image frames. When an  
image deviation is detected, the image data is processed  
with the frame memory by controlling the read/write timing  
of the frame memory so as to correct the image deviation.

15             In the device of the above publication, an  
acceleration sensor is provided to detect a camera motion.  
However, there is provided no moving mechanism which moves  
the imaging sensor based on the detected motion, so as to  
cancel the camera deviation having caused the image  
20    deviation.

       Japanese Laid-Open Patent Application No.  
2-103023 discloses a video camera deviation correcting  
device. The deviation correcting device includes  
horizontal and vertical line sensors which detect an image  
25    deviation caused by a camera deviation. Such an image

1 deviation is detected from a difference in image data  
between two frames in a sequence of continuously processed  
image frames. When an image deviation is detected, the  
imaging sensor is moved on a plane perpendicular to the  
5 optical axis of the video camera lens by a moving  
mechanism so as to correct the image deviation.

Japanese Laid-Open Patent Application No.  
6-46322 discloses an imaging apparatus having a deviation  
correcting function. The deviation correcting function of  
10 the imaging apparatus is applied to a video camera. A  
camera motion is detected by a vibration sensor. When a  
camera motion is detected, the imaging sensor is moved on  
a plane perpendicular to the optical axis of the video  
camera lens by a moving mechanism such that the center of  
15 the imaging sensor is aligned with the optical axis of the  
video camera lens.

The conventional techniques of the above  
publications are applied to the video cameras in which a  
sequence of image frames is continuously acquired and  
20 processed. However, it is very difficult to directly  
apply the video camera techniques to digital cameras in  
which a single frame of image data is acquired in an image  
acquisition time. In the case of digital cameras, it is  
necessary to correct a deviation of the imaging sensor of  
25 the digital camera within an image acquisition time for a

1 single frame, in order to eliminate the degradation of  
quality of a reproduced image due to a slight oscillation  
of the operator.

Further, in the conventional techniques of  
5 the above publications, there is no teaching about how to  
detect the magnitude and the direction of an imaging  
sensor deviation with a required level of accuracy, and  
how to move the imaging sensor based on the detection  
result in an effective manner so as to cancel the imaging  
10 sensor deviation. It is desirable to provide such new  
techniques for digital cameras, in order to incorporate  
therein the functions to effectively correct a deviation  
of the imaging sensor and to reliably prevent the  
degradation of quality of a reproduced image due to a  
15 slight oscillation of the operator in taking a photograph  
with the digital camera.

#### SUMMARY OF THE INVENTION

An object of the present invention is to  
20 provide a novel and useful deviation correcting apparatus  
and method in which the above-described problems are  
eliminated.

Another object of the present invention is  
to provide a digital camera deviation correcting apparatus  
25 which reliably prevents the degradation of quality of a

1 reproduced image of the digital camera due to a slight  
oscillation of the operator by correcting a deviation of  
the imaging sensor of the digital camera in an effective  
manner through an accurate detection of the imaging sensor  
5 deviation and a controlled movement of the imaging sensor  
based on the detection result.

Still another object of the present  
invention is to provide a digital camera deviation  
correcting method which reliably prevents the degradation  
10 of quality of a reproduced image of the digital camera due  
to a slight oscillation of the operator by correcting a  
deviation of the imaging sensor of the digital camera in  
an effective manner through an accurate detection of the  
imaging sensor deviation and a controlled movement of the  
15 imaging sensor based on the detection result.

The above-mentioned objects of the present  
invention are achieved by an apparatus for correcting a  
deviation of an imaging sensor of a digital camera in  
which an image of an object or a scene is formed on an  
20 image plane of the imaging sensor so that the imaging  
sensor outputs an image signal, which comprises: a  
rotation detecting unit which detects a quantity of  
rotation of the digital camera causing a deviation of the  
imaging sensor from a reference position to occur; a  
25 positional angle calculating unit which calculates a

1 change of a positional angle of the imaging sensor based  
on the rotation quantity detected by the rotation  
detecting unit; a target vector calculating unit which  
calculates a target vector based on the positional angle  
5 change calculated by the positional angle calculating  
unit, the target vector describing a magnitude and a  
direction of an inverse movement of the imaging sensor  
needed to reach the reference position and cancel the  
deviation; and a movement control unit which controls  
10 movement of the imaging sensor based on the target vector  
calculated by the target vector calculating unit, so that  
the imaging sensor is moved back to the reference position  
thus correcting the deviation, wherein the calculation of  
the target vector and the movement of the imaging sensor  
15 are executed within an image acquisition time for a single  
frame of the image signal.

The above-mentioned objects of the present  
invention are achieved by a method of correcting a  
deviation of an imaging sensor of a digital camera in  
20 which an image of an object or a scene is formed on an  
image plane of the imaging sensor so that the imaging  
sensor outputs an image signal, comprising the steps of:  
detecting a quantity of rotation of the digital camera  
causing a deviation of the imaging sensor from a reference  
25 position to occur; calculating a change of a positional

1 angle of the imaging sensor based on the detected rotation  
quantity; calculating a target vector based on the  
calculated positional angle change, the target vector  
describing a magnitude and a direction of an inverse  
5 movement of the imaging sensor needed to reach the  
reference position and cancel the deviation; and  
controlling movement of the imaging sensor based on the  
calculated target vector, so that the imaging sensor is  
moved back to the reference position thus correcting the  
10 deviation, wherein the calculation of the target vector  
and the movement of the imaging sensor are executed within  
an image acquisition time for a single frame of the image  
signal.

In the digital camera deviation correcting  
15 apparatus and method of the present invention, a quantity  
of rotation and/or a quantity of translation of the  
digital camera, causing a deviation of the imaging sensor  
from the reference position to occur, is detected by a  
rotation detecting unit and/or a translation detecting  
20 unit. A change of the positional angle of the imaging  
sensor is calculated based on the detected rotation  
quantity. A change of the quantity of translation of the  
imaging sensor is calculated based on the detected  
translation quantity. A target vector is calculated based  
25 on the calculated positional angle change and the



1     calculated translation quantity change, the target vector  
describing a magnitude and a direction of an inverse  
movement of the imaging sensor needed to reach the  
reference position and cancel the deviation. Movement of  
5     the imaging sensor is controlled based on the calculated  
target vector, so that the imaging sensor is moved back to  
the reference position thus correcting the deviation. The  
calculation of the target vector and the movement of the  
imaging sensor are executed within an image acquisition  
10    time for a single frame of the image signal. It is  
possible for the digital camera incorporating the  
principles of the present invention to provide good  
quality of a reproduced image as the degradation of  
quality of a reproduced image due to a slight oscillation  
15    of the operator is effectively prevented. It is possible  
that the apparatus and the method of the present invention  
effectively corrects a deviation of the imaging sensor of  
the digital camera through an accurate detection of the  
imaging sensor deviation and a controlled movement of the  
20    imaging sensor based on the detection result.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages of  
the present invention will become more apparent from the  
25    following detailed description when read in conjunction

1 with the accompanying drawings in which:

FIG. 1A is a block diagram of one embodiment of a digital camera deviation correcting apparatus of the present invention;

5 FIG. 1B is a flowchart for explaining one embodiment of a digital camera deviation correcting method of the present invention;

FIG. 2A is a block diagram of another embodiment of the digital camera deviation correcting apparatus of the present invention;

10 FIG. 2B is a flowchart for explaining another embodiment of the digital camera deviation correcting method of the present invention;

FIG. 3 is a diagram for explaining a camera coordinate system and a world coordinate system used to execute a positional angle calculation in the digital camera deviation correcting apparatus of the present invention;

20 FIG. 4 is a diagram for explaining the principles of a target vector calculation and an imaging sensor movement executed in the digital camera deviation correcting apparatus of the present invention;

FIG. 5 is a perspective view of one embodiment of an imaging sensor movement mechanism applicable to the digital camera deviation correcting

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1 apparatus of the present invention;

FIG. 6 is a top view of the imaging sensor  
movement mechanism of FIG. 5 when looking along a vertical  
rotation axis toward the origin of a camera coordinate  
5 system;

FIG. 7 is a side view of the imaging sensor  
movement mechanism of FIG. 5 when looking along an optical  
axis of the digital camera toward the origin of the camera  
coordinate system;

10 FIG. 8 is a side view of another embodiment  
of the imaging sensor movement mechanism applicable to the  
digital camera deviation correcting apparatus of the  
present invention;

FIG. 9 is a diagram for explaining the  
15 principles of the digital camera deviation correcting  
apparatus with the imaging sensor movement mechanism of  
FIG. 8 being incorporated therein;

FIG. 10 is a perspective view of one  
embodiment of a translation detecting device applicable to  
20 the digital camera deviation correcting apparatus of the  
present invention; and

FIG. 11 is a perspective view of one  
embodiment of a translation transmitting device applicable  
to the digital camera deviation correcting apparatus of  
25 the present invention.

1     DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

          A description will now be given of the preferred embodiments of the present invention with reference to the accompanying drawings.

5           FIG. 1A shows a digital camera deviation correcting apparatus embodying the present invention.

          In a digital camera to which one embodiment of the present invention is applied, an image of an object or a scene is formed on an image plane of an imaging  
10    sensor so that the imaging sensor outputs a digital image signal. The digital camera deviation correcting apparatus of the present embodiment is provided for correcting a deviation of the imaging sensor of the digital camera which may be produced by a slight oscillation of the human  
15    hand in taking a photograph using the digital camera.

          As shown in FIG. 1A, the digital camera deviation correcting apparatus of the present embodiment includes a rotation detecting unit 10 which detects a quantity of rotation of the digital camera which causes a  
20    deviation of an imaging sensor 9 from a reference position to occur. The imaging sensor 9 is comprised of a CCD (charge-coupled device) or a CMOS (complementary metal oxide semiconductor) device. The rotation detecting unit 10 may include a set of acceleration sensors provided to  
25    output signals indicative of accelerations of the digital

1 camera along an X axis, a Y axis and a Z axis of a world  
coordinate system, and a set of magnetic sensors provided  
to output signals indicative of magnetic fields of the  
digital camera along the X axis, the Y axis and the Z axis  
5 of the world coordinate system.

A positional angle calculating unit 12  
calculates a change of a positional angle of the imaging  
sensor 9 based on the rotation quantity detected by the  
rotation detecting unit 10. The positional angle  
10 calculating unit 12 may include a set of analog-to-digital  
converters and a microprocessor with a memory. A target  
vector calculating unit 14 calculates a target vector  
based on the positional angle change calculated by the  
positional angle calculating unit 12, the target vector  
15 describing a magnitude and a direction of an inverse  
movement of the imaging sensor 9 needed to reach the  
reference position and cancel the deviation. The target  
vector calculating unit 14 may include a set of  
digital-to-analog converters and a microprocessor with a  
20 memory.

In the digital camera deviation correcting  
apparatus of FIG. 1A, a drive control circuit 16 drives a  
displacement transmitting element 18 connected to the  
imaging sensor 9, based on the target vector calculated by  
25 the target vector calculating unit 14. The imaging sensor

1     9 is moved in the inverse direction by a given  
displacement by the displacement transmitting element 18.  
During the movement of the imaging sensor 9, the resulting  
displacement of the imaging sensor 9 given by the  
5     displacement transmitting element 18 is detected by a  
displacement detecting element 20 connected to the imaging  
sensor 9. A detection signal output by the displacement  
detecting element 20 is supplied to the drive control  
circuit 16. A closed loop control of the imaging sensor  
10    movement is carried out. Based on the detection signal  
supplied, the drive control circuit 16 continues to drive  
the displacement transmitting element 18 until the imaging  
sensor 9 reaches the reference position. The drive  
control circuit 16, the displacement transmitting element  
15    18 and the displacement detecting element 20 constitute a  
movement control unit which controls movement of the  
imaging sensor 9 so that the imaging sensor 9 is moved  
back to the reference position. Hence, the deviation of  
the imaging sensor 9 from the reference position is  
20    corrected by the movement control unit of the present  
embodiment.

      The displacement transmitting element 18 is  
comprised of a set of piezoelectric elements which change  
dimensions so as to transmit displacement to the imaging  
25    sensor 9 based on a drive voltage applied thereto. The

1 displacement detecting element 20 is comprised of a set of  
piezoelectric elements which produce a voltage output to  
the drive control circuit 16 when stressed by the imaging  
sensor 9.

5 In the digital camera deviation correcting  
apparatus of the present invention, the closed loop  
control of the imaging sensor movement is not necessarily  
required. An open loop control of the imaging sensor  
movement may be applied to the movement control unit of  
10 the digital camera deviation correcting apparatus. In  
such a case, the displacement detecting element 20 and the  
feedback line to the drive control circuit 16 as in the  
apparatus of FIG. 1A may be omitted. In any case, the  
deviation of the imaging sensor 9 caused by a slight  
15 oscillation of the operator can be corrected by the  
movement control unit.

It is possible for the digital camera  
deviation correcting apparatus of the above-described  
embodiment to provide good quality of a reproduced image  
20 as the degradation of quality of a reproduced image due to  
a slight oscillation of the operator is reliably  
prevented. It is possible to effectively correct a  
deviation of the imaging sensor 9 of the digital camera  
through an accurate detection of the imaging sensor  
25 deviation and a controlled movement of the imaging sensor

1 based on the detection result.

In the digital camera deviation correcting apparatus of the present embodiment, the calculation of the target vector and the movement of the imaging sensor  
5 are executed within an image acquisition time for a single frame of the image signal, which will be described later.

FIG. 1B is a flowchart for explaining a digital camera deviation correcting method embodying the present invention. The procedures of FIG. 1B are executed  
10 by the digital camera deviation correcting apparatus of FIG. 1A.

As shown in FIG. 1B, at a start, the digital camera is set in a waiting condition. Step S1 determines whether a power switch (not shown) of the  
15 digital camera is turned ON. When the power switch is turned ON, step S2 determines whether a release button (not shown) of the digital camera is set at a half position. When the release button is set at the half position, it is determined that the function of correction  
20 of a deviation of the digital camera is allowed to start.

When the result at the step S2 is affirmative, step S3 carries out the digital camera deviation correcting procedures with the digital camera deviation correcting apparatus of FIG. 1A. Namely, in the  
25 step S3, the rotation detection, the positional angle



1 calculation, the target vector calculation and the imaging  
sensor movement are executed by the elements of the  
digital camera deviation correcting apparatus of FIG. 1A.  
After the step S3 is performed, step S4 determines whether  
5 an image acquisition time for a single frame of image data  
has elapsed. Many digital cameras are adapted to use the  
NTSC standard, and the image acquisition time for one  
frame is normally 1/30 seconds. It is necessary to  
correct a deviation of the imaging sensor 9 of the digital  
10 camera within the image acquisition time for one frame.  
When the image acquisition time has not yet elapsed, the  
step S3 is repeated. When the image acquisition time has  
already elapsed, the step S2 is repeated.

When the result at the step S2 is negative,  
15 it is determined that the function of correction of a  
deviation of the digital camera is not allowed to start.  
Step S5 determines whether the power switch is turned OFF.  
When the power switch is turned OFF, the procedures of  
FIG. 1B terminate. When the result at the step S5 is  
20 negative (the power switch is ON), the step S2 is  
repeated.

According to the digital camera deviation  
correcting method of FIG. 1B, the digital camera deviation  
correcting procedures in the step S3 are carried out  
25 before the image acquisition of a single frame of image

1 data is complete. It is possible for the digital camera  
deviation correcting method of the above-described  
embodiment to provide good quality of a reproduced image  
as the degradation of quality of a reproduced image due to  
5 a slight oscillation of the operator is reliably  
prevented. It is possible to effectively correct a  
deviation of the imaging sensor 9 of the digital camera  
through an accurate detection of the imaging sensor  
deviation and a controlled movement of the imaging sensor  
10 based on the detection result.

FIG. 3 shows a camera coordinate system and  
a world coordinate system used to execute the positional  
angle calculation in the digital camera deviation  
correcting apparatus of the present embodiment.

15 As shown in FIG. 3, the digital camera to  
which one embodiment of the present invention is applied  
generally has a main body 1 and an optical system (camera  
lens) 2. A camera coordinate system ( $x, y, z$ ) and a world  
coordinate system ( $X, Y, Z$ ) are selected as shown in FIG.  
20 3. Suppose that, initially, the digital camera was in a  
reference position, in the sense that the center of the  
digital camera (or the center of the image plane of the  
imaging sensor therein) was at the origin of the world  
coordinate system, and all the axes of both the systems  
25 were aligned.

1           The main body 1 of the digital camera is  
fixed to the camera coordinate system. An optical axis of  
the optical system 2 is aligned with the z axis of the  
camera coordinate system, which was initially aligned with  
5   the Z axis of the world coordinate system. The Y axis of  
the world coordinate system is taken to accord with the  
direction of gravity. The Z axis is taken to accord with  
the direction of the north pole of the earth. The X axis  
of the world coordinate system is perpendicular to both  
10 the Y axis and the Z axis.

As shown in FIG. 3, in the digital camera,  
acceleration sensors 3, 4 and 5 are provided to output  
signals indicative of accelerations of the digital camera  
along the X axis, the Y axis and the Z axis, respectively.  
15 Further, magnetic sensors 6, 7 and 8 are provided to  
output signals indicative of magnetic fields of the  
digital camera along the X axis, the Y axis and the Z  
axis, respectively. The acceleration sensors 3, 4 and 5  
and the magnetic sensors 6, 7 and 8 constitute the  
20 rotation detecting unit of the digital camera deviation  
correcting apparatus of the present embodiment.

Assume that the digital camera was  
initially in the reference position at a time  $t$ , and a  
deviation of the digital camera (or a deviation of the  
25 imaging sensor therein) from the reference position is

1 produced at a following time  $(t+1)$  by a slight oscillation  
of the human hand in taking a photograph using the digital  
camera. In this assumption, as the deviating movement of  
the digital camera is considerably small in quantity, it  
5 is achieved only by rotation with no translation taking  
place. As a result of the above deviation, the digital  
camera is rotated from the reference position about the Y  
axis by a rotation angle  $\theta_y(t)$ , about the X axis by a  
rotation angle  $\theta_x(t)$ , and about the Z axis by a rotation  
10 angle  $\theta_z(t)$  to a new position. Specifically, the  
assumption is that the deviating movement of the digital  
camera from the reference position to the new position is  
achieved by three rotation steps: rotation of any point of  
the digital camera about the Y axis, rotation of the point  
15 of the digital camera about the X axis, and rotation of  
the point of the digital camera about the Z axis, in this  
order. Generally, the application of these rotation  
transformations can be represented by rotation matrices  
 $R_y(t)$ ,  $R_x(t)$  and  $R_z(t)$ , and the application of the inverse  
20 rotation transformations can be represented by the inverse  
rotation matrices  $R_y^{-1}(t)$ ,  $R_x^{-1}(t)$  and  $R_z^{-1}(t)$ .

In addition, assume that, at the time  $t$ ,  
the output signals of the acceleration sensors 3, 4 and 5  
were  $(A_x(t), A_y(t), A_z(t))$  (which is represented by an  
25 acceleration matrix  $[A(t)]$ ), and the output signals of the

1 magnetic sensors 6, 7 and 8 were  $(M_x(t), M_y(t), M_z(t))$   
 (which is represented by a magnetic field matrix  $[M(t)]$ ).

As the digital camera was initially in the  
 reference position at the time  $t$ , the following equation  
 5 can be obtained.

$$R_y(t)R_x(t)R_z(t)[A(t)] = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$

From the above equation, the rotation angles  $\theta_x(t)$  and  
 10  $\theta_z(t)$  of the imaging sensor are determined as follows.

$$\begin{aligned} \theta_x(t) &= -\sin^{-1} (A_z(t)), \\ \theta_z(t) &= \sin^{-1} (A_x(t)/\cos \theta_x(t)) \end{aligned} \quad (1)$$

Further,

$$\begin{aligned} 15 \quad \begin{bmatrix} M_x' \\ M_y' \\ M_z' \end{bmatrix} &= R_x(t)R_z(t)[M(t)], \\ \begin{bmatrix} 0 \\ M_y'' \\ M_z'' \end{bmatrix} &= R_y(t) \begin{bmatrix} M_x' \\ M_y' \\ M_z' \end{bmatrix} \end{aligned}$$

20 From the above equations, the rotation angle  $\theta_y(t)$  of the  
 imaging sensor is determined as follows,

$$\theta_y(t) = \sin^{-1} \{M_x' / \sqrt{(M_x'^2 + M_z'^2)}\} \quad (2)$$

The application of the rotation transformations at the  
 25 time  $(t+1)$  can be represented as follows,

1

5

10

15

25

1 each of the x axis, the y axis and the z axis of the  
camera coordinate system based on a drive voltage (or the  
target vector) supplied to the motors. Further, a  
translation transmitting device 9B is connected to the  
5 imaging sensor 9, and this translation transmitting device  
9B is comprised of a set of piezoelectric elements which  
apply translation to the imaging sensor 9 along each of  
the x axis, the y axis and the z axis of the camera  
coordinate based on a drive voltage (or the target vector)  
10 supplied to the piezoelectric elements. The rotation  
transmitting device 9A and the translation transmitting  
device 9B are provided in the movement control unit of the  
digital camera deviation correcting apparatus of FIG. 1A.

The dotted line in FIG. 4 indicates a  
15 deviation of the imaging sensor 9 from the reference  
position which is caused by a slight oscillation of the  
operator. For the sake of simplicity of description,  
suppose that the imaging sensor 9 at this time is rotated  
from the reference position (the solid line) to the  
20 deviating position (the dotted line) about the center "O"  
of the optical system 2 of the digital camera by a  
rotation angle " $\theta_y$ " due to the oscillation of the  
operator.

In this example of FIG. 4, a change of a  
25 positional angle of the imaging sensor 9, calculated by

1 the positional angle calculating unit 12 of the digital  
camera deviation correcting apparatus of FIG. 1A, is equal  
to the rotation angle " $\theta_y$ ". As being apparent from FIG.  
4, in order to correct the deviation of the imaging sensor  
5 9, application of rotation to the imaging sensor 9 about  
the y axis of the camera coordinate system by a rotation  
angle " $-\theta_y$ " is needed to be effected by the movement  
control unit of the apparatus of FIG. 1A. The rotation  
transmitting device 9A is driven by the movement control  
10 unit so that the imaging sensor 9 is rotated about the y  
axis by the rotation angle " $-\theta_y$ " through the rotation  
transmitting device 9A.

In the example of FIG. 4, a distance  
between the center "O" of the optical system and the  
15 center "O'" of the imaging sensor 9 along the z axis is  
represented by "f". This distance "f" is varying when a  
zooming function of the digital camera is performed, but  
the distance "f" can be calculated in accordance with the  
actual zooming amount when the zooming function is  
20 performed. The distance "f" can be considered the known  
quantity. In the example of FIG. 4, in addition to the  
rotation about the y axis, the center "O'" of the imaging  
sensor 9 is translated to the center of the deviating  
position along the z axis by " $f \cdot \sin^2 \theta_y$ " and along the x  
25 axis by " $-f \cdot \sin \theta_y \cdot \cos \theta_y$ " due to the oscillation of the



1 operator. Hence, in order to correct the deviation of the  
imaging sensor 9 into the reference position (the solid  
line in FIG. 4), application of translation to the center  
of the imaging sensor 9 along the z axis by " $-f \cdot \sin^2 \theta_y$ "  
5 and along the x axis by " $f \cdot \sin \theta_y \cdot \cos \theta_y$ " is needed to be  
effected by the movement control unit of the apparatus of  
FIG. 1A. The translation transmitting device 9B is driven  
by the movement control unit so that the center of the  
imaging sensor 9 is translated along the z axis by "-  
10  $f \cdot \sin^2 \theta_y$ " and along the x axis by " $f \cdot \sin \theta_y \cdot \cos \theta_y$ "  
through the translation transmitting device 9B.

Accordingly, in the example of FIG. 4, the  
target vector calculating unit 14 of the apparatus of FIG.  
1A calculates a target vector based on the positional  
15 angle change " $\theta_y$ ", the target vector describing a  
magnitude and a direction of an inverse movement of the  
imaging sensor 9 (including both the above-mentioned  
rotation and the above-mentioned translation) needed to  
reach the reference position and cancel the deviation.  
20 The inverse movement of the imaging sensor 9 is controlled  
through the rotation transmitting device 9A and the  
translation transmitting device 9B based on the calculated  
target vector, so as to move the imaging sensor 9 from the  
deviating position (the dotted line) back to the reference  
25 position (the solid line).

1                   In the above example of FIG. 4, the  
application of only the rotation with respect to the y  
axis has been considered. In addition, the application of  
only the translations with respect to the z axis and the x  
5   axis. The same principles can be extended to include the  
rotations with respect to the x axis and the z axis as  
well as the translation with respect to the y axis, so  
that the application of the rotation about each of the x  
axis, the y axis and the z axis as well as the application  
10 of the translation along each of the x axis, the y axis  
and the z axis is effected by the movement control unit of  
the apparatus of FIG. 1A.

                  In a case in which a translational  
displacement of the imaging sensor 9 can be detected by  
15 the apparatus of FIG. 1A and a change of the positional  
angle " $\theta$ " is very small, the approximation  $\theta = \tan \theta$  can  
be utilized in order to carry out the target vector  
calculation and the imaging sensor movement in the digital  
camera deviation correcting apparatus of FIG. 1A.

20                   FIG. 2A shows another embodiment of the  
digital camera deviation correcting apparatus of the  
present invention. In FIG. 2A, the elements which are the  
same as corresponding elements in FIG. 1A are designated  
by the same reference numerals, and a description thereof  
25 will be omitted.

1                   As shown in FIG. 2A, the digital camera  
deviation correcting apparatus of the present embodiment  
includes a translation detecting unit 11 and a translation  
quantity calculating unit 13, in addition to the elements  
5 of FIG. 1A.

The translation detecting unit 11 detects a  
quantity of translation of the digital camera along each  
of the X axis, the Y axis and the Z axis of the world  
coordinate system, which causes a deviation of the imaging  
10 sensor 9 from the reference position to occur. The  
translation detecting unit 11 is comprised of the  
acceleration sensors 3, 4 and 5.

The translation quantity calculating unit  
13 is connected to the target vector calculating unit 14.  
15 The translation quantity calculating unit 13 calculates a  
change of a quantity of translation of the imaging sensor  
9 based on the translation quantity detected by the  
translation detecting unit 11. The translation quantity  
calculating unit 13 may include a set of analog-digital  
20 converters and a microprocessor with a memory. The  
accelerations of the digital camera along the X axis, the  
Y axis and the Z axis of the world coordinate system are  
provided by the output signals of the acceleration sensors  
3, 4 and 5. A translational velocity of the imaging  
25 sensor 9 along each axis is calculated by taking the

1 integral of each of the accelerations with respect to  
time. A translational displacement of the imaging sensor  
9 along each of the X axis, the Y axis and the Z axis of  
the world coordinate system can be calculated by taking  
5 the integral of each of the velocity components with  
respect to time.

In the present embodiment, the target  
vector calculating unit 14 calculates a target vector  
based on the positional angle change calculated by the  
10 positional angle calculating unit 12 and on the  
translation quantity change calculated by the translation  
quantity calculating unit 13.

FIG. 2B is a flowchart for explaining  
another embodiment of the digital camera deviation  
15 correcting method of the present invention. The  
procedures of FIG. 2B are executed by the digital camera  
deviation correcting apparatus of FIG. 2A. In FIG. 2B,  
the steps which are the same as corresponding steps in  
FIG. 1B are designated by the same reference numerals, and  
20 a description thereof will be omitted.

As shown in FIG. 2B, the digital camera  
deviation correcting procedures of the present embodiment  
are essentially the same as the procedures of FIG. 1B  
except step S13. In the step S13, the rotation detection,  
25 the positional angle calculation, the translation

1 detection, the translation quantity calculation, the  
target vector calculation and the imaging sensor movement  
are executed by the elements of the digital camera  
deviation correcting apparatus of FIG. 2A. In addition to  
5 the operations of the step S3 shown in FIG. 1B, the  
translation detection and the translation quantity  
calculation are carried out by the element 11 and the  
element 13 of FIG. 2A. After the step S13 is performed,  
step S4 determines whether an image acquisition time for a  
10 single frame of image data has elapsed. When the image  
acquisition time has not yet elapsed, the step S13 is  
repeated. When the image acquisition time has already  
elapsed, the step S2 is repeated.

According to the digital camera deviation  
15 correcting method of FIG. 2B, the digital camera deviation  
correcting procedures in the step S13 are carried out  
before the image acquisition of a single frame of image  
data is complete. It is possible for the digital camera  
deviation correcting method of the above-described  
20 embodiment to provide good quality of a reproduced image  
as the degradation of quality of a reproduced image due to  
a slight oscillation of the operator is reliably  
prevented. It is possible to effectively correct a  
deviation of the imaging sensor 9 of the digital camera  
25 through a more accurate detection of the imaging sensor

1 deviation and a controlled rotational and translational  
movement of the imaging sensor based on the detection  
result.

FIG. 5 shows one embodiment of an imaging  
5 sensor movement mechanism applicable to the digital camera  
deviation correcting apparatus of the present invention.  
FIG. 6 is a top view of the imaging sensor movement  
mechanism of FIG. 5 when looking along the y axis toward  
the origin of the camera coordinate system. FIG. 7 is a  
10 side view of the imaging sensor movement mechanism of FIG.  
5 when looking along the z axis toward the origin of the  
camera coordinate system.

In the digital camera deviation correcting  
apparatus incorporating the imaging sensor movement  
15 mechanism of FIG. 5 therein, the acceleration sensors 3, 4  
and 5 and the magnetic sensors 6, 7 and 8, which  
constitute the rotation detecting unit 10 of the digital  
camera deviation correcting apparatus of the embodiment of  
FIG. 1A, are provided. The 3D (three-dimensional)  
20 rotation components of a change of the positional angle of  
the imaging sensor 9 from the reference position are  
detected, and the imaging sensor movement mechanism of  
FIG. 5 achieves an inverse rotation of the imaging sensor  
9 in the 3D manner so as to correct a deviation of the  
25 imaging sensor 9 and move the imaging sensor 9 back to the

1 reference position.

As shown in FIG. 5, in the digital camera to which the present embodiment is applied, an image of an object or a scene is formed through a camera lens 21 onto an image plane of the imaging sensor 9 (comprised of the CCD) so that the imaging sensor 9 outputs a digital image signal. The digital camera deviation correcting apparatus of the present embodiment is provided for correcting a deviation of the imaging sensor 9 which may be produced by a slight oscillation of the human hand in taking a photograph using the digital camera.

The camera coordinate system  $(x, y, z)$  is taken to the digital camera in a manner similar to that of FIG. 3. Preferably, the origin "O" of the camera coordinate system  $(x, y, z)$  accords with the center of the optical system (or the focal point of the camera lens 21). In the imaging sensor movement mechanism of FIG. 5, a set of motors 33, 34 and 35 are provided to respectively apply rotation to the imaging sensor 9 about the y axis, the x axis and the z axis of the camera coordinate system based on a target vector. FIG. 6 shows a connection of the motor 34 and the motor 35 which are held in the digital camera, and FIG. 7 shows a connection of the motor 33 and the motor 34 which are held in the digital camera.

25 As shown in FIG. 6, the motor 35 has a

1 rotary shaft fixed to the center of the imaging sensor 9  
(the CCD), and the rotary shaft of the motor 35 is rotated  
about the z axis of the camera coordinate system. The  
motor 35 has a base secured to a first rectangular surface  
5 of an L-shaped member 36. The L-shaped member 36 includes  
a second rectangular surface which is perpendicular to the  
first rectangular surface and parallel to the yz plane.  
The motor 34 has a rotary shaft fixed to the second  
rectangular surface of the L-shaped member 36. The rotary  
10 shaft of the motor 34 is rotated about the x axis of the  
camera coordinate system. When the rotary shaft of the  
motor 34 is rotated, the imaging sensor 9 and the motor 35  
are rotated together about the x axis through the L-shaped  
member 36.

15 As shown in FIG. 7, the motor 34 has a base  
secured to a first rectangular surface of an L-shaped  
member 37. The L-shaped member 37 includes a second  
rectangular surface which is perpendicular to the first  
rectangular surface and parallel to the xz plane. The  
20 motor 33 has a rotary shaft fixed to the second  
rectangular surface of the L-shaped member 37. The motor  
33 has a base secured to the main body of the digital  
camera (which is not shown in FIG. 7). The rotary shaft  
of the motor 33 is rotated about the y axis of the camera  
25 coordinate system. When the rotary shaft of the motor 33



1 is rotated, the motor 34, the motor 35 and the L-shaped member 37 are rotated together about the y axis through the L-shaped member 37.

Similar to the calculation of the  
5 positional angle change of FIG. 3, the digital camera was initially in the reference position at the time t, and the rotation angles  $\theta_x(t)$  and  $\theta_z(t)$  of the imaging sensor 9 are determined in accordance with the above equations (1). The rotation angle  $\theta_y(t)$  of the imaging sensor 9 is  
10 determined in accordance with the above equation (2).

The application of the rotation transformations at the time (t+1) can be represented by the above equation (3). From the above equation (3), a change of the positional angles of the imaging sensor 9 of  
15 the digital camera between the initial time t and the following time (t+1) can be determined.

Assuming that the change of the positional angles of the imaging sensor 9 is determined as  $\theta^t_x(t+1)$ ,  $\theta^t_y(t+1)$  and  $\theta^t_z(t+1)$ , the motors 34, 33 and 35 are  
20 controlled based on the target vector to respectively apply rotation to the imaging sensor 9 about the x axis by  $-\theta^t_x(t+1)$ , about the y axis by  $-\theta^t_y(t+1)$  and about the z axis by  $-\theta^t_z(t+1)$ , so as to cancel the deviation of the imaging sensor 9 and move the imaging sensor 9 back to the  
25 reference position.

1                   FIG. 8 shows another embodiment of the  
imaging sensor movement mechanism which is applicable to  
the digital camera deviation correcting apparatus of the  
present invention.

5                   In the digital camera deviation correcting  
apparatus incorporating the imaging sensor movement  
mechanism of FIG. 8 therein, a 2D (two-dimensional) gyro,  
which constitutes the rotation detecting unit 10 of the  
digital camera deviation correcting apparatus of the  
10 embodiment of FIG. 1A, is provided. The 2D gyro detects  
angular velocities of the imaging sensor 9 with respect to  
the x axis and the y axis of the camera coordinate system.  
The 2D rotation components of a change of the positional  
angle of the imaging sensor 9 from the reference position  
15 are detected, and the imaging sensor movement mechanism of  
FIG. 8 achieves an inverse translation of the imaging  
sensor 9 in the 2D manner so as to correct a deviation of  
the imaging sensor 9 and move the imaging sensor 9 back to  
the reference position. In this case, the rotational  
20 movement of the digital camera is considerably small, and  
it is achieved only by translation with no rotation taking  
place.

FIG. 9 shows the principles of the digital  
camera deviation correcting apparatus with the imaging  
25 sensor movement mechanism of FIG. 8 being incorporated

1     therein.

As shown in FIG. 9, in the digital camera to which the present embodiment is applied, an image of an object is formed through the camera lens 21 onto the image plane of the imaging sensor 9 (comprised of the CCD). The center of the image of the object on the image plane of the imaging sensor 9 is indicated by "O" in FIG. 9. The reference position (the solid line in FIG. 9) of the imaging sensor 9 is indicated by "P1" in FIG. 9. A distance between the center of the imaging sensor 9 and the center of the camera lens 21 is indicated by "f" in FIG. 9.

Suppose that the digital camera is rotated by a rotation angle " $\theta$ " with respect to the optical axis of the camera lens 21 (or the z axis of the camera coordinate system) due to a slight oscillation of the operator. The rotation angle " $\theta$ " is very small. The image plane of the imaging sensor 9 is moved from the reference position "P1" to a deviating position "P2" (the dotted thin line in FIG. 9) due to the deviation of the imaging sensor 9. The center of the image of the object on the image plane of the imaging sensor 9 at the deviating position "P2" is indicated by "O'" in FIG. 9.

In the example of FIG. 9, in order to correct the deviation of the imaging sensor 9, application

1 of translation to the center of the imaging sensor 9 by  
the distance  $d = f \cdot \tan \theta$ . After the translation is  
applied, the imaging sensor 9 is moved from the deviating  
position "P2" to a corrected position "P3" (the dotted  
5 thick line in FIG. 9). As the rotation angle " $\theta$ " is very  
small, the approximation  $\theta = \tan \theta$  can be utilized.  
Hence, application of the translation to the center of the  
imaging sensor 9 by the distance  $d = f \cdot \theta$  is needed to be  
effected by the movement control unit of the apparatus of  
10 FIG. 1A.

Assuming that the change of the positional  
angles of the imaging sensor 9 is calculated as  $\theta^t_y(t+1)$   
and  $\theta^t_z(t+1)$ , the application of translation to the  
imaging sensor 9 along the y axis by  $-f \cdot \theta^t_y(t+1)$  and along  
15 the z axis by  $-f \cdot \theta^t_z(t+1)$ , so as to cancel the deviation  
of the imaging sensor 9 and move the imaging sensor 9 back  
to the reference position. The output signals of the 2D  
gyro are the angular velocities of the imaging sensor 9,  
and the change of the positional angles can be calculated  
20 by taking the integral of each of the velocity components  
from the time  $t$  to the time  $(t+1)$ .

In the embodiment of the imaging sensor  
movement mechanism of FIG. 8, a piezoelectric element 38  
is secured at one end to the base of the imaging sensor 9  
25 (the CCD). The piezoelectric element 38 is secured at the

1 other end to a first surface of an L-shaped member 39.  
The piezoelectric element 38 is provided to apply  
translation of the imaging sensor 9 along the y axis of  
the camera coordinate system. The L-shaped member 39 has  
5 a second surface which is perpendicular to the first  
surface and parallel to the y axis. A piezoelectric  
element 40 is secured at one end the second surface of the  
L-shaped member 39, and secured at the other end to the  
main body of the digital camera. The piezoelectric  
10 element 40 is provided to apply translation of the imaging  
sensor 9 along the x axis of the camera coordinate system.  
Accordingly, the imaging sensor movement mechanism of FIG.  
8 achieves an inverse translation of the imaging sensor 9  
in the 2D manner so as to correct a deviation of the  
15 imaging sensor 9 and move the imaging sensor 9 back to the  
reference position.

FIG. 10 shows an embodiment of a  
translation detecting device which is applicable to the  
digital camera deviation correcting apparatus of the  
20 present invention.

As shown in FIG. 10, a range finder 41 is  
provided on the digital camera, and this range finder 41  
measures distances of objects from the digital camera  
along three lines, indicated by the three arrows in FIG.  
25 10, which are all perpendicular to each other. The range

1     finder 41 acts as the translation detecting device which  
detects a quantity of translation of the digital camera in  
the digital camera deviation correcting apparatus of the  
present invention.

5             In the digital camera deviation correcting  
apparatus with the translation detecting device 41  
incorporated therein, the acceleration sensors 3, 4 and 5  
and the magnetic sensors 6, 7 and 8 are also provided.  
The acceleration sensors 3, 4 and 5 and the magnetic  
10    sensors 6, 7 and 8 constitute the rotation detecting unit  
of the digital camera deviation correcting apparatus of  
the present embodiment. The positional angle calculation  
is carried out based on the output signals of these  
sensors 3 through 8 in the same manner as the above-  
15    described positional angle calculation with reference to  
FIG. 3.

           In the digital camera deviation correcting  
apparatus with the translation detecting device 41  
incorporated therein, a translation quantity calculation  
20    is carried out based on output signals of the range finder  
41 as follows.

           As described above, the range finder 41  
outputs signals indicative of distances between objects  
and the digital camera in the three directions. If three  
25    distant fixed objects in the three directions are given,

1 the range finder 41 outputs the signals indicating the distances of the fixed objects from the digital camera.

Suppose that the range finder 41 has output the distance signals  $[dx(t), dy(t), dz(t)]$  at the initial  
5 time  $t$  and the distance signals  $[dx(t+1), dy(t+1), dz(t+1)]$  at the following time  $t+1$ . A change of quantity of translation of the imaging sensor of the digital camera which may be produced by a slight oscillation of the operator is represented by  $[-(dx(t+1)-dx(t)), dy(t+1)-$   
10  $dy(t), -(dz(t+1)-dz(t))]$ . Hence, if the positional angle change is not considered, the target vector describing a magnitude and a direction of an inverse translation of the imaging sensor 9 needed to reach the reference position and cancel the deviation is represented by  $[dx(t+1)-dx(t),$   
15  $-(dy(t+1)-dy(t)), dz(t+1)-dz(t)]$ .

In the digital camera deviation correcting apparatus with the translation detecting device 41 incorporated therein, the target vector calculating unit calculates the target vector based on the calculated  
20 positional angle change and on the calculated translation quantity change as in the embodiment of FIG. 2A.

FIG. 11 shows one embodiment of a translation transmitting device which is applicable to the digital camera deviation correcting apparatus of the  
25 present invention.

1                   As shown in FIG. 11, piezoelectric elements  
42, 43 and 44 are linked together such that the  
piezoelectric elements 42, 43 and 44 are aligned with the  
x axis, the y axis and the z axis of the camera coordinate  
5       system. One end of the piezoelectric element 42 is fixed  
to the main body of the digital camera. One end of the  
piezoelectric element 44 is fixed to the motor 33 of the  
imaging sensor movement mechanism of FIG. 5. By supplying  
a drive signal from the drive control circuit to each of  
10   the piezoelectric elements 42-44, each piezoelectric  
element achieves a translational movement of the imaging  
sensor 9 along one of the x axis, the y axis and the z  
axis of the camera coordinate system so as to cancel the  
deviation of the imaging sensor 9.

15                  The piezoelectric elements 42, 43 and 44  
act as the translation transmitting device which achieves  
a translational movement of the imaging sensor 9 based on  
the calculated target vector in the digital camera  
deviation correcting apparatus of the present invention.  
20   By utilizing the translation transmitting device of FIG.  
11 and the rotation transmitting device of FIG. 5 in  
combination, the movement control unit in the digital  
camera deviation correcting apparatus of the present  
invention can be constituted. This movement control unit  
25   controls rotational and translational movements of the



1     imaging sensor 9 based on the calculated target vector, so  
that the imaging sensor 9 is moved back to the reference  
position thus correcting the deviation.

          Further, the present invention is not  
5     limited to the above-described embodiments, and variations  
and modifications may be made without departing from the  
scope of the present invention.

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